The use of site index for monitoring site quality and productivity of the Sunt plantation in the Blue Nile

Case Study: Riverain Forest along the Blue Nile

Lembwa Forest

By

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Dedication

To my parents,

Father Osman shahali, Mother Alawia

To my brothers, to my sisters

To my friends

Maysra shahali

Declaration

I, Maysra Osman Shahali, here by declare that, except where otherwise referred this Dissertation is my own work and has not been submitted in whole or in parts for Degree award at any other university or as report to any institution.

Signature: *Maysra shahali*

Date: **2005**

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Abstract:

The Forests are rapidly dwindling and ground vegetation has disappeared from extensive areas, creating various environmental hazards, forest products scarcity and land productivity decline. These results are largely attributed to the management approaches currently adopted in Sudan, which are criticized as being inefficient and unsustainable.

Riverain forests lie long both banks of the Blue Nile as detached area, have from a very unique forest ecosystem. *Acacia nilotica* (Sunt) has been found the most valuable timber producing species. Since the establishment of the plantations in 1935, the species was managed on thirty year's to approach normal structure and attain sustainable production. They were for some times managed for sustained yield throughout the first thirty years rotation (1935-1964), presently the forests are described as declining in productivity.

A difference in growth trends and production potentials exists between two site quality classes. Stands in both quality classes are at present managed with similar objectives and on the same rotation. But they produce timber of different quality and size.

The main objective of the present study is to evaluate the productivity of the site Sunt plantation and the possibility for their management on sustainable production basis.

The area / age distribution over the first rotation (1935-1964) area related to total area, indicates a stable and balanced structure of organized distribution of *Acacia nilotica* stands in space (area) and time (age). This structure is an indication of a sustainable form of management. Being grouped in five years age classes, the difference between groups in area is very small from the average (11520/6 =1920 feddan / 5 years group), The second thirty years rotation (1965-1994) indicates a wide variation between the actual areas within 5-years groups and the expected average of (1920-2000) feddan. Similar trends or area / age distribution were detected for individual forests.

In Lembwa forest the area / age structure in a series of one year age groups was developed for 13 compartments in 1987. The thirteen compartments were delineated into three units of one year age-group in 2004.

All the compartments in Lembwa forest were inventories in 1987 and in 2004 for site index values and quality class assessment, using top height against age. The compartments indicated a change Q.C.I during the 1987 to Q.C.II in the 2004 inventory as a result of failure to control felling or top

height trees. This was verified by measurement of the diameters of large stumps and projection of d b h estimations to height estimated. The estimated height resulted in adjustment of compartments Quality class to class I.

الخلاصة:

تضائلت الغابات في السودان بوتيرة سريعة مما تسبب فى تدهور بيئي وقلة في انتاج الغابات وادت الي تدهور انتاجية الاراضي، ويعزي هذا الي حد بعيد الي الاساليب الادارية المتبعة حاليا في هذا المجال. والفرضية السائدة هي ان هذا التدهور يعزي الي حد بعيد الي التخطيط الضعيف وسوء الادارة وان الاساليب الادارية غير مجدية وعاجزه عن تحقيق الاستدامة.

تمتد الغابات النيلية علي ضفتي النيل الازرق والتي تعتبر نظاما بيئيا فريدا، تغطي مساحة واسعة من الاراضي وهي ذات اهمية اقتصادية حيوية في السودان والتي تعمل كحماية طبيعية وتلعب دورا مهما في البيئة .لقد ظلت غابات السنط منذ انشائها تدار علي نظام الانتاج المستدام حيث حققت نجاحا، ولكن بدأ تدهور الانتاج والابتعاد عن تحقيق الانتاج المستدام بسبب فقدان التكوين العمري المتتالي وتناقص الكثافة الشجرية للفدان عند نهاية الدورة من خمسين شجرة في الفدان الي اقل من ذلك (125 شجرة في الهكتار) والتي تدار في دورة عمرها 30 سنة لانتاج فلنكات السكة حديد وغيرها من الاخشاب المنشورة. هناك اختلافات جوهرية في النمو بين موقعين مختلفين. ووقوفا علي هذه المواقع نجد ان الغابات تدار حاليا لنفس الاهداف وبنفس عمر الدورة برغم انها تنتج منتجات مختلفة في الجودة والحجم.

في الغابات النيلية اشارت الدورة الاولى الي التوزيع المناسب والمتوازن لاشجار السنط في المساحة والعمر مما ادي الاستدامة الادارة ووجود اختلافات بسيطة في المساحة بالنسبة للمجموعات المقسمة الي خمسة صفوف عمرية اما الدورة الثانية فاشارت الي وجود اختلافات كبيرة بين المجموعات العمرية الخمسة. اما بالنسبة لغابة اللمبوه في عام 1987 كانت المساحة مقسمة ال13 مربوع و13 عمر ولكن في 2004 تحولت تلك المرابيع الي 3 مجاميع عمرية.

كل مرابيع اللمبوه التي حصرت في 1987و2004 وضعت في مؤشر الموقع باستعمال الارتفاع والعمر صنفت المرابيع بان هنالك تغيير من Q.C.I خلال 1987 الي Q.C.II في 2004 . وتوضح النتائج الفشل في التحكم في القطع او الاشجار السائدة ويتضح ذلك من من الارومات قياس القطر عند الصدر وتقدير الارتفاع والذي دال على ان المرابيع الموجودة هي (Q.C.I).

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CHAPTER 1
Introduction

1.1 General

Sudan is the largest country in Africa with a total area of one million square mile, approximately 2.5 million square kilometers, about 250.58 million hectares, extending between latitudes 4°N and 22°N and longitudes 22° E and 39° E. Sudan is bounded on the east by Red Sea and on other sides by nine African countries. Sudan is characterized by diverse climatic conditions, from desert (0 -100 mm rainfall per annum) to savannah (200 – 850 mm rainfall per annum) and tropical rainforests (up to 1500 mm per annum). The country is divided administratively into 26 states.

The forests and wood lands cover 17.68% of the total land area (FAO, 2000). The forest reserves approximate 12.5 % of the total area of the Sudan (CNS 1992 – 2002). However, the Sudan aims to increase the reserved forest areas up to a minimum of 25% of the area of the country.

The estimated population in 2004 was 39,148,162, giving the country an average population density of 17 persons per sq km (43 per sq mi). The White Nile and the Blue Nile are the most densely populated areas. Sudan's population is growing at a rate of 2.64 percent annually.

The Sudan is divided into five ecological zones as based on rainfall (Table1.1)

Table1.1 Vegetation classification in relation to rainfall.

Vegetation	Rainfall	Area in (ha)
Desert	0-75 mm	90 208 00 (36 %)
Semi desert	75-300 mm	50111000 (20 %)
Low rainfall savannah	300-900 mm	60139000 (24 %)
high rainfall savannah	900-1500 mm	30070000 (12 %)
Flood plains mountain vegetation	1500-2000 mm	20046000 (8 %)

(Source: FOSA 2001)

1.2 Climatic zone

Sudan is characterized by a wide range of climate variation, which vary from desert in the northern of Sudan, where it seldom rains, through a southward belt of varying summer rainfall, to an almost equatorial type of rains in the extreme south west, where the dry season is very short. In central Sudan division of seasons can be observed and the duration of these seasons vary with latitude.

1.3 Land and Resources

Sudan has a maximum length of 2,250 km from north to south and the extreme width of the country is about 1,730 km. It is divided into three separate natural regions, ranging from desert in the north, covering about 30 percent of the area of Sudan, through a vast semiarid region of steppes and low mountains in central Sudan, to a region of vast rain forest and swamps (As Sudd region) in the south. Major topographical features of Sudan are the Nile River, its headstreams the White Nile and Blue Nile, and the tributaries of these rivers. The White Nile traverses the country from the

Uganda border to a point near Khartoum, where it joins the Blue Nile to form the Nile proper. The Blue Nile rises in the Ethiopian Plateau and flows across east central Sudan. Another important tributary of the Nile is the ‘Aṭbarah, which also rises in the Ethiopian Plateau. The Libyan Desert a barren waste broken by rugged uplands covers most of Sudan west of the Nile. The Nubian Desert lies in the region east of the Nile and the ‘Aṭbarah. The Red Sea Hills are located along the coast. The highest point in Sudan, Kinyeti (3,187 m.a.s.l), is in the southeast.

Table 1.2 shows land use classes by area.

Table 1.2 Land area classifications in Sudan

Item	**Area in (000 Hectare)**
Total area	250.58
Land area	237.443
Area under water	12.986
Arable land	84.034
Cultivated land	17.471
Uncultivated land	66.563
Forest and wood land	64.360
Other	49.569

Source: Administration of statistics and information (1995)

1.4 Economical activities

Population has grown from 10.26 million in 1956 to 25.6 million in 1993; and 30.3 million in 2002. The annual growth rate has increased from 1.9 % to 2.7 %, one of the highest in the world.

Some 70 % of economically active people are engaged in agricultural or pastoral activities, another 21% are employed in services, and only 9 % have jobs in manufacturing, construction, mining and civil service.

1.5 Forest resources in Sudan

Forests are essential as local, national and global resources. At the local levels, communities in and around the forests are always dependent on forest products. Unplanned use of the forests altered the composition of many forests of today as a result of continuous extraction. At the national level, economies have depended and continued to rely on access to fuel, lumber and timber products. Despite increasing substitution by alternative materials, the demands for timber continue to rise. However, the survival of forests and woodlands is fundamental to the continued functioning of other environmental systems. (FOSA, 2001).

Forest products and services play a crucial role in the economy of Sudan and the life of its people. FOSA (2001) stated that about 40 tree species constitute fodder trees particularly during dry season. Wood fuels constitute 80 % of the total national energy.

Gum Arabic and other tree gums are among the important foreign exchange earners; poles and sawn timber for construction and furniture are also supplied by forests.

The environmental and social roles played by Sudan forests are even more pronounced; forests and woodlands are the first and the last defense line against desert encroachment southwards.

Riverain forests lie along both banks of the Blue Nile as detached areas. They form a very unique forest ecosystem covering a vast area and are of vital economic importance for the economy of Sudan and its nature conservation. They played important environmental roles. They provide fuelwood, poles and sawn timber for construction and furniture. They protect the Nile system and its watershed and soil against wind and water erosion. Riverain forests are valuable both in terms of their direct use and indirect values. Examples of the forests uses, which indirectly support economic activities include prevention of soil erosion, wildlife habitat and microclimate protection.

Acacia nilotica (Sunt) plantations of the Blue Nile flood basins form significant resource with an area exceeding 13 Thousand Fadden (5.7 Thousand hectares). The contribution of *Acacia nilotica* species to the total sawn timber production in northern Sudan is estimated at 40-50%. Its contribution to the production of round timber may be considered as second to the Eucalyptus. The latter continues to be the major source of round timber in the Sudan. Sunt also adds substantial volume to the production of fuelwood estimated at 10-15 % of the country's total production. Sunt has been found the most valuable timber producing species. An ability to regenerate successfully on flooded sites along the Nile and its tributaries, coupled with timber properties that satisfy most of the utilization standards make the species the most important in the economy of the Sudan. Sunt timber is preferably used in various utilization practices including railway sleepers, heavy construction, turnery, boat building and fuel. Its properties are very attractive to such uses that require hard and strong mechanical properties, (Elsiddig and Hetherington 1985).

Exploitation of the natural sunt forests started at the beginning of the last century when the first sawmill was installed in 1901 for trials of railway sleeper production. However, the industry of sleeper production progressed very slowly. During the period, 1930-1940 fairly good progress in agricultural development enhanced further railway construction that resulted in more consumption of sunt timber for railway sleepers and fuelwood. The initial small-scale reforestation programmes of Sunt forests resulted in the first even-aged plantation in the Sudan but large-scale conversion of the natural crop into plantations only started in 1938.

1.6 Statement of Problem

Forests in Sudan are rapidly dwindling and ground vegetation has disappeared from extensive areas, creating various environmental hazards, forest products scarcity and land productivity decline. These results are largely attributed to the management approaches currently adopted in Sudan, which are criticized as being inefficient and unsustainable. Many reports have warned about the declining forest resources and emphasized on the importance of quantifying and appraising the remaining resources. Sustainable management of these resources was emphasized on many occasions.

The plantation of Sunt forests along the Blue Nile is not exceptional. They were for some times managed for sustained yield throughout the first thirty years rotation (1935-1964) presently the forests are described as declining in productivity.

Differences in growth trends and production potentials between two site quality classes of the Riverain forests are observed from a pilot sampling. Stands in both quality classes are at present managed with similar objectives and on the same rotation. However, they produce timber of different quality and size. To manage all forests on fixed rotations (30 years), irrespective of site quality may result in error in production planning. The present study is an attempt to evaluate differences between these classes, and to use the site classification to evaluate site quality productivity.

1.7 Objectives

The main objective of the present study is to evaluate the productivity of the site Sunt plantation and the possibility for their management on sustainable production basis.

1. The study aims at classification of the sites into quality classes and to facilitate reorganization of the present forests into quality class.

2. To set a system based a site index for monitoring and evaluation of the capability of each site through time

CHAPTER 2

Literature Review

2.1 The management plan

The plan usually describes the goals of the forester and a schedule of activities for the woods. Generally the larger the forest acreage and the more different conditions of soils and tree sizes in the woods, the more details are needed in the plan (Osmaston 1968). Where there are major differences in various sections of the woods in the form of productivity classes, the needed forestry activity will likely be quite different (Husch *et al*. 1972). Therefore, the plan or activities will vary for each of the different major conditions found; dividing the woods into sections or compartments allows the forester to treat them separately. The plan will tell the forester when the available time will be spent for the best future returns. In other words, it sets priorities for work which needs to be accomplished.

There are many things which may be made a part of a plan of action; naturally few plans will contain all of them. The following are items to consider in developing any plan as stated in many texts (Osmaston 1968).

- Maps of the property showing the boundaries and the wooded portions of the property clearly separated using time scale or productivity level. When the woods have been divided into several compartments for management purposes, each compartment should be shown along with the acreage and the conditions on the compartment, such as the major kinds of tree, the size-class of the trees, the site characteristics and the production potentials.

- A description of the management compartment including the major kinds of trees, the most important size-class of the trees, some idea of the amount of merchantable volume by tree kinds and sizes, and what forestry practices are needed.
- For those with trees at or near mature size, information on available markets prices and product specifications should be compiled and plans for sales and contracts developed.
- Thoughts should be given to road layout and construction so any roads or trails will have permanent value for future harvests and forestry activities as well as a current sale. Roads can coiside with boundaries of major classes.
- Plans and activities for other values such as wildlife, water, and any other use of interest to the owner may be considered.
- A date should be established for a review of the current plans; the date will depend upon the forest conditions and how much activity will take place in the near future. In the case of Sunt plantation the thinning schedules every three years starting at age six years is an example (Jackson 1958).

A management plan is a tool to help the forester set goals, and assign priorities to forest management activities. Systematic planning is a step to productive forests and satisfactions gained from forest regardless of how large or how small are the acreage. The management plan facilitates monitoring and evaluation of the forest conditions and their suitability to defined management objective. The management goals set for the management of Sunt plantation includes timber production and protection of the Nile ecosystem (Elsiddig 2002).

The management of Sunt plantation on the higher slopes or the lower slopes is based on the site quality and individual tree size-class's development. The rotation aged has been changed from 30 years based on clear felling to variable age–rotation of individual trees based on selection system, (Elsiddig and Abdelgadir. 1998).

2.2 Forest planning and management in Sudan

The early history of Sudan forestry is one of heavy exploitation of natural forests without reservation and rehabilitation. This type of mismanagement continues until a mid-term forest management planning started and the first working plan for some Riverain forests came into operation in 1929 and a complete working plan covered the period 1929-1933 for only six reserved areas and twelve unclassified forests (Elsiddig and Hamid 2000).

Agreement on reservation program was settled with the issuance and enactment of Sudan forest policy 1932 of the central and provincial forest ordinances. The first proper management plan was prepared for Riverain forests. Booth (1948) defined the approach for plan preparation as conservation plan. The objective was directed towards the continuous development of equal area of annual plantation as the basis for sustainable management. This working plan was followed by preparation of many forest working plans in different areas of Sudan.

At the same time no management plans were made for the natural forests except for very few reserved natural forests. All management activities executed within the natural forest reserves are mainly concerned with protection through patrolling system. Such approaches turned the forest management into a punishing tool rather than a development mechanism

(Vink, 1998). Moreover, the few existing management plans have clearly failed to achieve their intended objectives, e.g. sustainable production of railway sleepers from the Riverain forests because they were narrowly defined and didn't consider the various needs and interest of different stakeholders, particularly local communities. Such management plans are not based on site understanding nor on the conditions around the forests such as people needs and the type and size of the products needed.

The serious error in forest uses have come about from an attempt to manage the whole forest on a human-time scale i.e. to plan timber cutting for human needs according to fixed rotations 15 years, 20 years or 30 years management plans, irrespective of whole ecological conditions (site quality, changing climatic condition, human induced changes, etc...). These numbers of years, present an irrelevant cycle in the whole forest functioning. There is a need for revising the conventional timber management and considering more ecologically oriented management approaches in order to consider site and site quality. Recent inventories (1986-1997) indicated a decline in the average number of stems per fadden in most of the forest reserves as a result of creaming and selective felling by the formal authorities and by the local communities (Elsiddig 2002). Also there is an observed decline in volumes of fuelwood produced due to lopping of higher trees and cutting of branches (Elsiddig and Hamid 2000).

2.3 Sunt

Acacia nilotica (Sunt) has been found the most valuable timber producing species. The Riverain forests, which can be considered, as the most unique

ecosystem in the world, should managed to provide an array of uses and services (Elsiddig and Hamid 2000).
The current decision of using the species mainly for timber production is a decision typically based on narrow objectives and on the financial returns. Alternative uses of the forest ecosystem and the many environmental values are subsequently lost (Elsiddig and Hamid 2000). This approach for timber production as the main use may be the reason for forest degradation and productivity variation over rotation.

Forest managers are sometime challenged by the task to transform national-level goals into forest-level prescription, yet more difficulties are expected to arise from the fact that global emphasis on forest management planning is being based not only on timber production but also on values such as biodiversity conservation, carbon sequestration, wild life and amenities (Elsiddig and Hamid 2000). Considering such multiple goals assist in satisfaction of sustainability objective and maintenate or the productive capacity of the forest (Osmaston 1968).

2.4 The utilization of Sunt in Sudan

Tree utilization objectives of Sunt are based on timber production as recognized in the working plans (Booth, 1948; Jackson, 1958; Foggie 1968). They include:

- Production of railway sleepers.
- Sawn timber for local uses.
- Fuelwood.

Sleepers production consists of the Sudan railway sleeper of 2.3 meters length and 25x12.5 cm cross-sectional area, and the Sudan Gezira Board light rail sleepers of 1.2 meter length and 20x10 cm. This kind of product constitutes the most important produce of all sawn timber production from the species (Elsiddig and Hetherington, 1985). The management of the species for these production targets necessitates careful treatments of the Sunt plantation over successive periods to end at 30 years of age with the best quality log size-classes (Jackson 1958). Selection of the best quality trees of the largest 50 trees per feddan at age 12 years to be maintained as final felling trees was recommended (Jackson 1958; foggie 1968).

Swan timber production from small sized log (25 cm at small end), and from the waste of sleepers production, includes bed units, stools, lintels for construction purposes and boat industry. Fuelwood production includes the remaining waste of sawmills and the branch wood of sizes smaller than 25 cm in diameter (Elsiddig and Hetherington 1985). These products come as second priority in the management objectives and come from small sized trees, which are not the target for final fellings.

The main product, railway sleepers, constitutes the major objective of the management plan defined to be attained at thirty years rotation (Elsiddig, 1980). Jackson (1958) described the time-scale activities conducted in sequence of thinning operations every three years starting at age six years and ends up to 50 trees per feddan after the fifth thinning cycle, reached at age 20 years. The best quality trees were retained at age 20 years and maintained up to age 30 years for final felling and also constitute the site quality trees being the largest and best formed. Each potential to be selected as top height tree for site index evaluation (Elsiddig 1980). Elsiddig (2002) defined these best trees as site indicators. Any 4-10 trees per 0.1 hectare provide a measure of the site index and the quality of the site.

2.5 Site classification

Different tree species growing on the same site or the same species growing on different sites exhibit great variability in growth and volume productivity (Carmean1975; Hetherington and Elsiddig, 1983/84). These variations stimulated the development of various concepts, methods and techniques for site evaluation and productivity assessment, (Carmean1975; Elsiddig1980). Such variations in growth and productivity provide the basis for monitoring and evaluation of difference in major products over time.

2.5.1 Site types and quality classes

Three site types were identified on the basis of the topography and the soil of the flood basins, and given the local names Karab, Maya Slope and Gerf slope (Jackson, 1958; Elsiddig and Hetherington, 1985; Elsiddig 2002). Polymorphic site index curves were constructed for each site type and eventually combined into two groups on the basis of their shape producing one set of curves for the Gerf slopes and one set for the Karab and Maya (Hetherington and Elsiddig 1983 / 84).

Analysis showed that a logical grouping into classes resulted in an improvement in tree volume prediction and volume tables were prepared by Elsiddig (1980).for:

- Quality class 1: all gerf slopes and karab slopes and Maya of site index 21 - 25.
- Quality class 2: karab slopes and Maya of site index 17 - 20.

The site quality description in this case is first based on physical factors i.e. to geographical factor, then biological factors are based on top height measurement. Tree size-classes and saw logs production for railway sleeper's production were found to exhibit differences between quality class I and quality class II. Hence, quality classification is a measure of differences in productivity.

Productivity can also be measured indirectly by looking at how well plants are growing on different soils or topographic classes. Differences can qualitatively be evaluated based on experience. It can be understood that when this idea is applied to how well trees are growing on a site, the productivity is called site quality. The idea is that sites with the fastest growing trees have the most productive conditions (Assmann 1970). Trees on sites with productive soils will be taller and larger in diameter than trees of the same age growing on less productive soils. For this reason top height is used as a measure for site and used for site classification. It implies that top height trees must be conserved throughout the rotation and during successive rotation to facilitate accurate site index evaluation selected fifty largest trees per feddan according to Jackson provided such condition.

2.5.2 Site Index

Site quality can be estimated by means of a site index. The relationship between the top height and age of trees on one particular site is called its site index (Schumacher, 1933 Carmean, 1975). It's important to recognize that within a forested property of any size, there will no doubt be a good deal of variation in the soil found there and its productivity. Therefore, it's very likely that parts of forest will have different site quality (Carmean, 1975).

Of all the indirect measures investigated, the rate of height growth has been the most practical, consistent, and useful indicator of site quality with respect to timber production. The standard practice has been to define site index in terms of the total height of the dominants, the largest and full-crowned trees in a stand. These trees capture the most light, moisture, and nutrients in a stand. Numerically, site index is the total height of the dominant trees in a stand at specified ages, 20 years in case of Sunt (Elsiddig 1980).

2.5.3 Site index curve

Regardless of whether the method of site definition to be used is the direct or indirect approach, a necessary perquisite is a set of site index curves. Because of this and because of the primary importance of site index in forest productivity classification and forest management, a great deal of work has been directed to methods of site index curve construction and their use in site index prediction. The original approach was graphical, based on the assumption of an anamorphic growth pattern (Bruce 1926, Bruce and Schumacher 1950). The approach is named "the harmonized curve method" as it employs a scatter diagram of the observations and harmonization of the family of curves on a proportional basis. It was very useful for long time as basis of yield studies and forest management. It is described in many textbook of menstruation (Bruce and Schumacher 1950, Carron 1968).

Site index information has been collected for most of the major tree species. The productivity of different soils for one particular species is represented by means of a graph or curve, (Kocher and Blanc . 1996). The “site index” is the height of the trees at the index age, which can be from 16 to 30 years, depending on the site index classification system used. The curves can be constructed for sites of different site quality and show tree height growth versus tree age. (Kocher and Blanc.1996).

2.5.4 Estimating Site Index

Estimating the site index for forest requires finding out how fast the trees are growing. This requires knowing how tall the trees are and how old they are (Splechtan 2001). It is important to choose trees that have been dominant during their whole lifetime. This is because trees which have been overtopped by others will have slower growth and therefore, be shorter for their age than the dominant trees in the stand (Kocher and Blanc. 1996). It implies that selection of trees which are not dominant will under estimate the site index and accordingly under estimate the site quality (Boyer 2001).

The height of the tree can be measured fairly easily. Trees can be measured from the ground with a special instrument, known as clinometers. It can also be very easily measured by using tree measuring stick for short trees at early ages. Site index values can be presented in a graph or in tables (Elsiddig 1980). To estimate site index, the age of the site tree is taken and located on the horizontal axis of the graph. A line is drawn straight up. Then the height of the site tree is located on the vertical axis and a straight line is drawn across. (Kocher and Blanc. 1996). The use of site index tables facilitates reading of site index against age value, at different ages to provide for site quality and yield in past and future (Curtis 1972)

2.5.5 Site Quality Classes

Site quality class, usually numbered in Roman numericals from I (best) to III (worst) is a grouping of site indexes used to determine among other things, the productivity rates for the stand. It also determines whether or not it can be zoned as (timber production zone). In most counties, on sites (Site Class I to III), site class is also used to determine which of the compartment "Practice Rules" may apply on the forest (Kocher and Blanc. 1996).

Site quality class is a similar idea to site index, but slightly different. In general, the many different site indeces for each species have been lumped together into a series of site quality classes. These site classes are known as site class I through III. For Sunt plantation qualitative classification has been applied as Gerf, Karab and Maya. then site indeces of gerf (site index 21 – 25) are grouped as quality class I. for the karab slopes and Maya, site index (21-25) are classified as quality class I, while site index 16 – 20 are grouped as Q.C.II (Elsiddig 1980).

The most productive sites, those capable of growing the fastest trees, are grouped together into site class I, while the least productive are lumped into site class III (Kocher and Blanc. 1996). Therefore, site quality classes are usually used to compare sites within specific regions and forest types. A site class property cannot be assumed to have the same growth potential along the outer Karab slopes as a site class property in the gerf of the Riverain along the Blue Nile.

While the measure of site index for forest stand is relatively straight forward, a determination of site class requires localized information to be factored (Kocher and Blanc, 1996). Because taxes and timber harvest regulations are involved, it may be needed to rely on the professional judgment of a professional forester to accurately determine the property's site class.

2.6 Site Quality and Stand characteristics

Site quality tells how much timber a forest can potentially produce. The productivity of forest is defined in terms of the maximum amount of volume that the forest can produce over a given period. Site quality is measured as an index related to this timber productivity, (Nyland. 1983). Since total volume accumulation for site assessment is not easy, top height is the alternative measure for site quality assessment.

It is very important to understand that the productivity of forest varies greatly by site. On one site very good growth may be observed, while on another site, the same species at the same age may grow poorly (Nyland. 1983). Site quality can be changed by fertilization, vegetation control or irrigation. Only highly intensive treatment can make a productive site out of a poor one (Nyland 1983)

2.7 Density and Stocking

Density is a measurable attribute of a stand. Stand density is a measure of how many trees are growing per unit area. Together, site and density tell how much timber can be produced, as well as what kind of wood quality can be expected at harvest time (Nyland 1983). Stand density can describe how much a site is being used and the intensity of competition between trees for the site's resources (i.e., water, light, nutrients and space). At higher densities, the growth rates of individual trees slow down because there are more trees competing for the site's limited resources (Bennett 1970).

Stocking refers to the adequacy of a given stand density to meet some specified management objective. Hence, stands are often referred to as understocked or fully stocked (Briegleb 1952, Bick ford 1957). Stocking is a relative concept - a stand that is overstocked for one management objective may be understocked for another (Nyland 1983).

2.8 Volume

Since many objectives relate to volume, it is often used as a measure of density. Volume is interpreted in relation to some standard, such as the volume represented in a yield table, and is given as a percentage of stocking for a specified objective.

2.9 Thinning

Once trees crowd out, it is important to open stands back up as soon as possible. Thinning should be conducted in Riverain forests and should be implemented as the word “thinning from below” applies, so the end result will be closed canopy. Commercial thinning can be implemented at age 6 to 20 years, depending on the site quality (Jackson 1958).

Site quality can be measured as height that trees will reach by a certain age (usually 20 years). A good *Acacia nilotica* site might be 25 meters at 20 years. A typical forestry thinning provides space for the residual trees to grow but does not allow sunlight to penetrate to the ground; additional tree removal is, therefore, in order. Basal area is the total cross-sectional area of wood in the stand, expressed as square meter per hectare or feddan. The forestry rule of thumb is usually to thin a stand until the site index is about equal with increasing age. For Sunt, thinning stops at age 20 when 50 trees per feddan are remaing (Jackson 1958).

2.10 Over Thinning

Five thinnings used to be applied for *Acacia nilotica* plantation, namely at ages six, nine, twelve, fifteen and twenty years (Jackson 1958). By the twentieth year the crop would be reduced to fifty trees per Fadden (125/ha) at approximately 9 x 9 meter spacing (Elsiddig 2002)

It was a common practice in the past to select and mark the final felling crop (50 trees per Fadden) early in the development stages of the *Acacia nilotica* plantations (Jackson 1958). It was an approach for tree improvement since the best growing, large-stemmed trees with straight long boles were selected, usually after the third thinning at age 12 years. These trees might have been seed source. Successive thinnings are concentrated on removal of trees other than the marked 50 trees per feddan until age twenty. This practice of management resulted in production of large sized saw logs such that an average production of 1.2 - 2.0 railway sleepers per average tree at the final felling age 30 years. Approximately, 75-80 sleepers were produced per feddan (Jackson 1958, Elsiddig 2002). Ahmed (1976) provides guidelines for thinning of *Acacia nilotica* stand along the Blue Nile which are compatible with Jackson (1958).

With time, the practice of final felling, crop selection and marking was abandoned. At present, the final crop is usually less than fifty trees per Fadden and the final felling trees are not the largest. This might be because of heavy thinnings, or that successive thinning continued beyond the age of twenty years. Ahmed (1997) observed large stumps of recently felled trees in stands approaching final felling, while small-sized trees left. This condition of selection of large trees for felling may result in reducing the top height value and the site quality.

CHAPTER 3

Study Area

3.1 Selection criteria

The study area extends along the Blue Nile containing the Riverain Forests Reserves Lembwa, Gazair and Gelgani forests selected to represent the study area.

Lembwa, Gazair and Gelgani forests were selected as case studies for this research because of the following:

Good representatives of the Riverain forest in a typical Nile basin with characteristic bottom of the basin (Maya), basin slopes nearest the river (Gerf slope) and the slopes adjoining the clay plains in land (Karab slopes).

3.2 Location

The study area is located in the fung region of the Sennar state, between latitudes12° 5̀ -14° 7̀ N and longitudes 35° 42̀- 42° 58̀ E. It includes 182 sunt forests alternating on both banks of the Blue Nile in a narrow discontinuous strip of width traversed by the Blue Nile. the area of the forests approximates 59763.477 Feddan. The northern boundary of the area is about 307 kilometer south of Khartoum the capital of the Sudan.

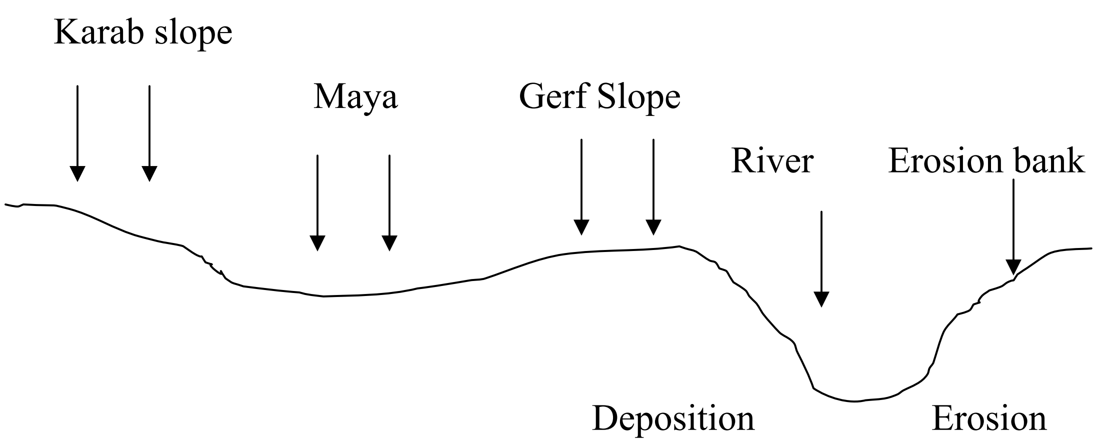
The study area Lembwa and Gelgani are located in the western bank of the Blue Nile, while Gazair is located on the eastern bank.

The total area of Sennar state is 40680 Squire KM (9,700,000 fed) (4073918.52 hectares).The total area of Lembwa forest is 804 fed (337.6 hectares).

3.3 Topography

Flood basin of the Blue Nile has been created by meandering action on one bank and deposition of sand and silt on the other bank of river beds. The existing flood basins of the Blue Nile are believed to have been created by this meandering activity (Jackson 1958).The bottom of the basin is locally known as (Maya) which means a shallow depression often flooded. The basin slopes nearest to the river are locally known as (gerf slope) and the slope adjoining the clay plains in known as (karab slopes). (Figure 3.1)

Figure 3.1 Diagrammatic transect across a meander of the Blue Nile basin



3.4 Geology

The underlying geological formation of the whole area is the Nubian series. The topography of the terrain is generally flat featureless clay plain with a gentle slope from south to north. The shallow basins in the flood plain are considered as old meander channel of the river, which has been cut off. The basins are generally flatter in the northern part of the area, and in the southern part are better defined and deep (Elsiddig and Hetherington 1985).

3.5 Climate

The climate of the area generally taken on average as being like the climate of the southern Blue Nile, it is usually characterized by maximum annual temperature. All the area falls within the savannah region characterized by short rainy season and a longer drier period. As the area lies within very narrow geographical limits, its climate is rather uniform.

3.5.1 Temperature

The area is characterized by cold dry weather from November to February and hot dry weather from March to June. The mean daily maximum temperature is lower in January (about 30º C day temperature) and highest in May (about 41º C day temperature).

The mean daily minimum is lowest in January (About 13-14 C° night temperature) and highest in May (about 24-25C° night temperature). It means that January is the coolest and May the hottest month (Table 3.1).

Table 3.1 Mean figures of temperature for area

Parameter	Month	Degree C
Mean daily maximum	May	41
2nd peak	October	30
Mean daily minimum	June	24-25
Mean daily minimum	January	13-14

Bushara (1990).

3.5.2 Winds

During the rainy season, the prevailing winds are from the south east and during the dry season from the north to east.

3.5.3 Relative humidity

The relative humidity trend is influenced by the temperature and rainfall, reaching its maximum in August and minimum in April-May, its highest value (70-80%) in August and the lowest (08-09%) in April.

3.5.4 Rain fall

The rainy season starts in June and ends in October with a savannah type of distribution having its peak in August. Occasional light showers fall in May. The average annual rainfall of the area, falling within a range of 550 - 620 mm per annum.

Lembwa Riverain forests fall within the savannah region characterized by average annual of 400-500 mm.

3.6 Soil

The soils of the basins are recent, immature alluvial deposits. They are called (montmorillonitic clays) that have the property of swelling when moistened and contracting when dry to form cracks up to one meter deep.

The soil of the flood basins of the Blue Nile exhibit some variations from that of the clay plains. Here the soils may be classified into three major soil groups related to the basin topographic classes.

The dominant soil of the "Maya" is typical of the dark, cracking clays believed to have been brought from the clay plains by water run-off. It is a black, clay soil that cracks widely in the dry season. The "karab slopes" are eroded slopes characterized by a higher content of sand and gravels exposed as a result of erosion. The "gerf slopes "on the other hand have deep, permeable silt deposits known to be the most fertile type of soils.

The clay plain soils and the flood basins soils have been influenced mainly by weather factors (Bunting and lea 1962). The deep underlying geological rock of the ancient basement complex had no effect on their formation. (Elsiddig and Hetherington, 1985).

3.7 Vegetation cover

The vegetation in the Riverain forests is *Acacia nilotica* (Sunt) in the major area. Normally fringing the pure *Acacia nilotica* stand on the flood basin. On the karab side outside the basin Sunt gives way to less moisture demanding species. These species are *Balanites aegyptiaca* (higlig), *Acacia nubica* (laot), *faidherbia albida* (Haraz)

Grasses and herbs in the basins are various and numerous. The perennial sedge, *sorghum sp* (Adar) is found in the basins. Other species that can be mentioned include the herbs *cassia senna* (Sana makka), which is eat by animals with relish when dry, and *solanum nigrum* (gibbein), which occur at the fring of the forest particularly on the karab side.

3.8 Population

The study area is inhibited by a number of tribes; in Lembwa some are of Arabic origin mainly (kenana - Arakiin). Others are from African origin (Felata, Nuba, and Fur).

CHAPTER 4
Materials and Methods

4.1 General

Lembwa, Gazair and Gelgani forests in Sennar State were selected to represent Riverain forests along the Blue Nile.

4.2 Data source

The data used in this study includes some of previous data of the Sunt Forest Inventory (Jackson, 1958) and Forest Inventory (1994) which was carried out by the Forests National Corporation (FNC) in collaboration with the Food and Agriculture Organization of the United Nations (FAO). in addition the annual inventories based on final year forestry students training (1986-1987-2004) and others data collected by the present study.

4.3 Field procedure

The main task was to measure tree variables useful in the classification of the site quality in the forest and to facilitate comparison between sites. The data was collected from *Acacia nilotica* at Lembwa, Gazair and Gelgani forests in Sennar State.

4.4 Data collection

A decision on the sample size, the distribution of the sampling units and the procedure for their measurements was an essential step in the design of the sampling plan, and achievement of acceptable precision.

4.5 Pilot survey

The fieldwork started with pilot survey of the area, which consists of 12 compartments in Lembwa forest to have an overall view of the different compartments and their boundaries, distribution of trees and stocking. In addition, the age of compartment was recorded from compartments records. The results of the pilot survey gave the information required for inventory planning.

4.6 Sample tree measurements

In this study, a sampling procedure was adopted for collection of data based on systematic line plot sampling. The distance between them was 150 meter and between sample plots within lines was 100 meters giving representation of 0.1 ha for every 1.5 ha. The first sample plot selected was 60 meters from the boundary. The sample plot was a circle with radius equals 17.8 meters. When the sample plot center was located, the circle boundary was fixed by marking all the trees with distance greater than 17.8meter.

In each plot all trees were marked at breast height (1.3 meters) over bark. Each tree was assigned a number to assist later selection of sample trees, for top height. The selected trees were measured for (d.b.h) in cm using a caliper. Sample tree data was recorded on forms designed for the purpose. Data was recorded for each sample plot for each compartment. The site type of the sample plot was recorded as Gerf, Karab or Maya.

4.6.1 Diameter measurement

Diameter measurement was taken over bark at reference height (1.3) meter from ground level, with the caliper, read and recorded to the nearest mm. The caliper was held perpendicular to the stem axis, taking care to avoid

knot, swellings and similar deformations and after having removed any growing or other foreign objects (creapers) from the bark.
Multi-stemmed trees are recorded as separate trees if the forking occurs below reference height (1.3) meter. Stems below 7.0 cm were nots recorded.

4.6.2 Top height

In each sample plot the total height of each of the four largest (d.b.h) trees was measured and records in meter. The selected trees were measured for height using a hypsometer. The age was recorded from plantation records.

The average height of the top height trees and the age were recorded.

4.6.3 Stump Diameter measurement

Stump Diameter measurement was taken over bark at ground level of the stump and recorded to nearest mm, four largest stumps were measured in each plot.

4.7 Analysis

The measurement of tree diameter facilitated selection of the four largest trees to be measured for top height.

The top heights of the four largest trees were averaged to in an average top height for the sample plot, which was recorded Tater against age. Top height value and age were used to estimate the site index value based on site type (Gerf, Karab and Maya) using Elsiddig (1980) site index tables. This procedure was applied for the top height and age data of the 2004 and data of 1987 measurements. The 1987 data represented the first rotation for plantation established 1957, the data of the 2004 represent plantation established between 1986–1989. The procedure facilitated estimation of site index value of previous and present management.

The value of site index facilitated estimation of site quality class and assessment of changes in productivity values between the two rotations.
The estimated top height for the inventory (for the plantation of 1985 – 1989) was used for site index and site quality estimation.

For comparison between the measured top height (of year 2004 data) and the estimate top height (stump data) the results are presented in tables to investigate differences between estimates of site index and site quality (for year 2004) using top height from sample trees and estimated top height from sample stumps. It is assumed that the presence of large stumps indicates removal of large trees that their heights represent top height trees. Measured stump diameters in each plot were averaged and used for estimation of average dbh using Eltayeb (1985) equation (equation 4.1). Then average top height was estimated using Hetherington and Elsiddig (1983/84) equation (equation 4.2)

$d_{BH} = 6.1248+0.7396\ d_{GH}$ (equation 4.1). (Eltayeb 1985)

Where:

d_{GL} = Tree diameter at ground level {stump}.

d_{BH} = Tree diameter at breast height.

By using the equation, it is possible to calculate trees diameter at breast height if its diameter at ground level is known. For height determination, the relationship between height and diameter at breast height is used. This relationship could be calculated by using the height – diameter value of *Acacia nilotica*. The relationship is expressed by the following equation**:**

$h = 8.09 + 0.53\ d - 0.0033\ d^2$ (equation 4.2) (Hetherington and Elsiddig 1983 / 84)

CHAPTER 5

Result and discussions

5.1 Introduction

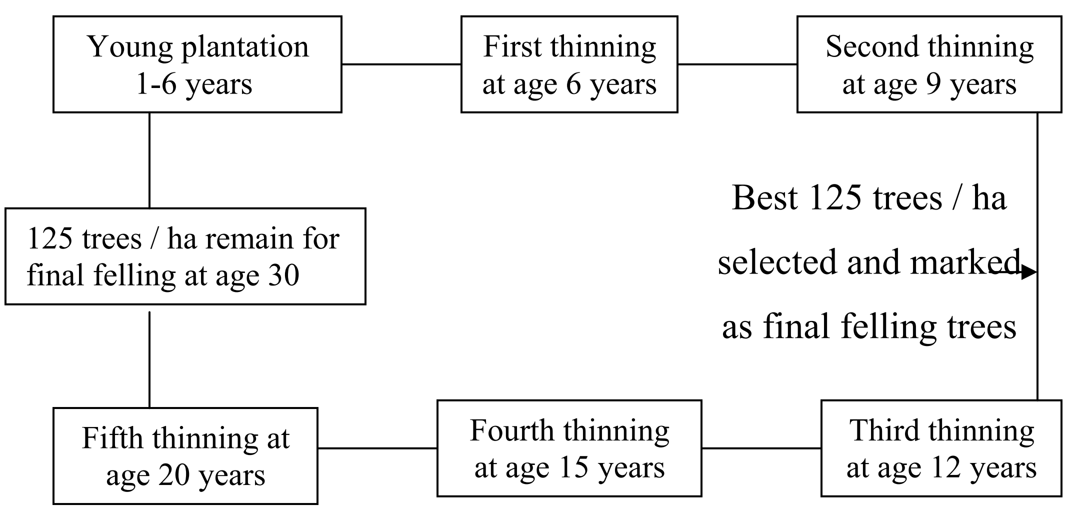
This chapter documents the research results and provides interpretation and discussions on each of the research aspects. The analysis and results contained in this study comprise one of the pilot broad-based micro level examinations of decision support information.

5.2 Yield regulation

All the *Acacia nilotica* plantations exist between Sennar and Demazin are managed on 30 years rotation length for the production of railway sleepers as the main management objective. To satisfy this system of management on sustainable basis, the plantations are subjected to regular thinning regime and yield prescription.

Jackson (1958) recommended five thinnings *Acacia nilotica* plantation, namely at ages 6, 9, 12, 15 and 20 years (Figure 5.1).

Figure 5.1 Diagramatic illustration of thinning schedule for Sunt plantation over age 1-30 years.



At each thinning, a yield table is followed as guide for the number of trees per hectare to be left after the removal of the trees marked for thinning

At age twelve years and before executing the third thinning, it is usually prescribed that the best fifty trees per feddan (125 trees per hectare) are selected and marked as the final felling trees (Jackson 1958). It is assumed that at this age, the best recognized trees reflect the site productivity and they will remain as the site quality trees through the rotation. By the twentieth year the crop would be reduced to fifty trees per feddan (125/ha) at approximately 9 x 9 meter spacing. These trees are conserved and protected until age thirty years when finally felled.

Measurements made on these trees, using top height and age, facilitated determination of site quality. That means, measurements on trees selected from this group of 50 trees per feddan (125/ha) at any age between 12 years and 30 years indicate the site quality. The site type's delineation facilitates good management decision based on stands organization on area/age basis to regulate yield by area aiming at bringing yield by equal areas with the minimum differences in yield.

Site index curves constructed by Elsiddig (1980) and yield table guides developed by Eltayeb 1985 are used to evaluate the trend of changes in Sunt stands site index values and stand characteristic for selected stands during the rotations.

The evaluation of the structure of area / age over the first rotation of Sunt plantation (1935-1964), second rotation (1965-1994) and extrapolation of the data over first 10 years (1995-2005) of the third rotation (1995-2024) provided measurements on the status of area / age distribution as an indicator to the criteria of sustainability. Values of top height and age for each area/age group represented the means for the quality class assessment. The objective is to follow the trend of area/age distribution and to use this aspect as management tools for improving the yield over time.

Lembwa, Gezir and Gelgani forests were used to identify sites, to develop links between top height and site index values and assess site quality values as a measure of productivity. Variation in productivity between the first rotation and the second indicates changes in site index values as from first rotation to second. These changes in site quality are also associated with changes in area / age distribution as from first to second rotation. The results presented were discussed in the context of mismanagement and their impacts.

The results are presented in three impacts of mismanagement:

1- Yield regulation system.
2- Site quality evaluation.
3- Productivity assessment.

5.3 Yield regulation system

The management during the first 30 years rotation followed the planned activity according to Booth (1949) work plan (1948 – 1958), Jackson (1958) plan over the period (1958 – 1968) and Foggies (1968) plan over the period

(1968 – 1978). However between 1978 – 1996 the activities relied on felling programs

5.3.1 Total forest area

The plantation of *Acacia nilotica* along the Blue Nile flood basins were managed over thirty years rotation for the production of railway sleepers and other small-sized sawn timber. The Sunt was managed to approach normal structure and attain sustainable production.

Yield planning continued to be regulated on annual area basis (Jackson1958; foggie 1968; Elsiddig 1980, Eltayeb1985 Elsiddig 2002). Although the situation of forest structure satisfied a good level of sustainable yield during the first rotation length 1935-1964 (Figure 5.2) deviations from sustainable yield was experienced during the second rotation 1965-1994 (Figure 5.3).

Figure 5.2 shows that area/age distribution over the first thirty years rotation (1935-1964) indicates a stable and balanced structure of organized distribution of *Acacia nilotica* stands in space (area) and time (age). This structure is an indication of a sustainable form of management. Being grouped in five years age classes, the difference between groups areas from the five years age group average (11520/6 =1920 feddan / 5 years group) is very small, as shown in Table 5.1

Table 5.1 five years - age groups area difference from the average of five years during first rotation (1935-1964).

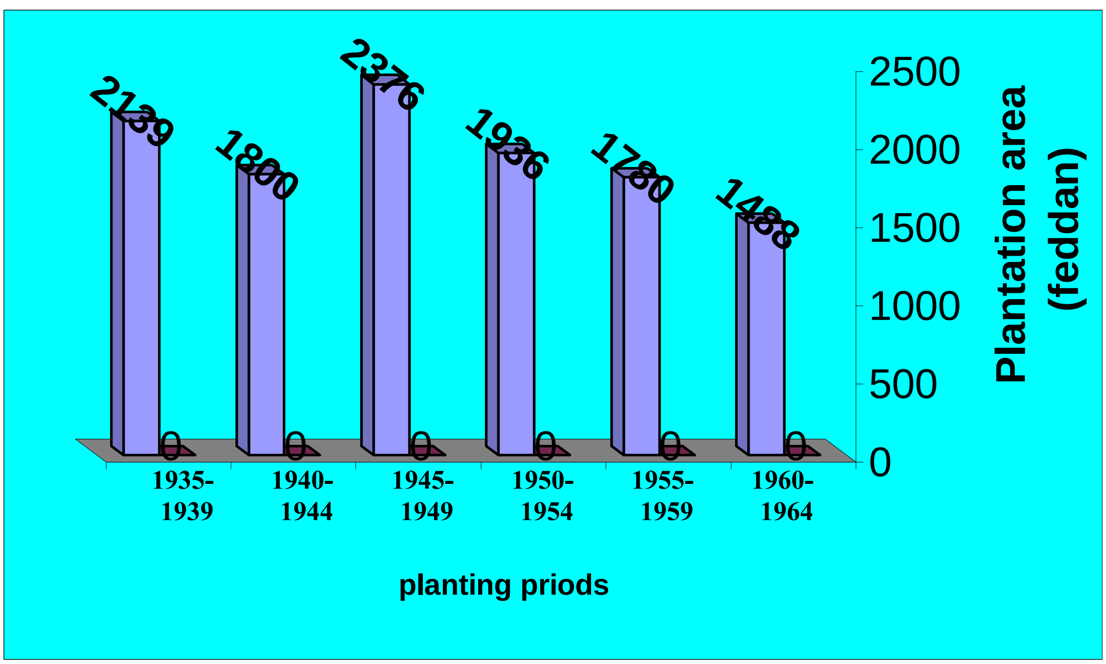
Average area feddan / 5 years	Plantation dates	Age years	Plantation area feddan / 5 years	Deference from average feddan

1920	1935-1939 1940-1944 1945-1949	26-30 21-25 16-20	2189 1800 2376	+ 269 - 120 + 456
	Total		6365	
	1950-1954 1955-1959 1960-1964	11-15 6-10 1-5	1939 1780 1488	+16 -140 -432
	Total		5207	

Source: **1985 inventory and (Jackson 1958)**

During the first rotation, the area of younger crop (young 15 years) age group, planted during 1950-1964, constitutes 45% of the total forest crop area, while the older one (age group 1935-1949) constitutes 55%. Figure 5.2 shows that the area/age distribution to great extent balanced

Figure 5.2 *Acacia nilotica* age class distribution 1935-1964



So urce: 1985 inventory and (Jackson 1958)

It may be good that the old crop (age group 1935-1949) occupied larger area than the younger age group (1950-1964). Yield regulation by area can then be adjusted by felling areas close to the annual average of 384 feddan, or 1920 feddan per five years group, leaving the rest of the area of old crop for continuous adjustment. The records of annual coupes during 1965-1975 show that about 400 feddan was annually felled and regenerated which is approximately the annual average for felling.

However, the area of annual coupes planted during 1965-1969 should have been reflected in the second rotation to approach 1920-2000 feddan for the five years age group 1965-1969 when this age group reached 26-30 years of age during 1990-1994 (the second rotation) accordingly each of the other 5 years age groups should approach the average 1920 feddans.

The area of the old crop is declining while the area of the young crop or bare land is increasing, as shown in Table 5.2.

Table 5.2 five years age-groups area difference from average during second rotation (1965-1994).

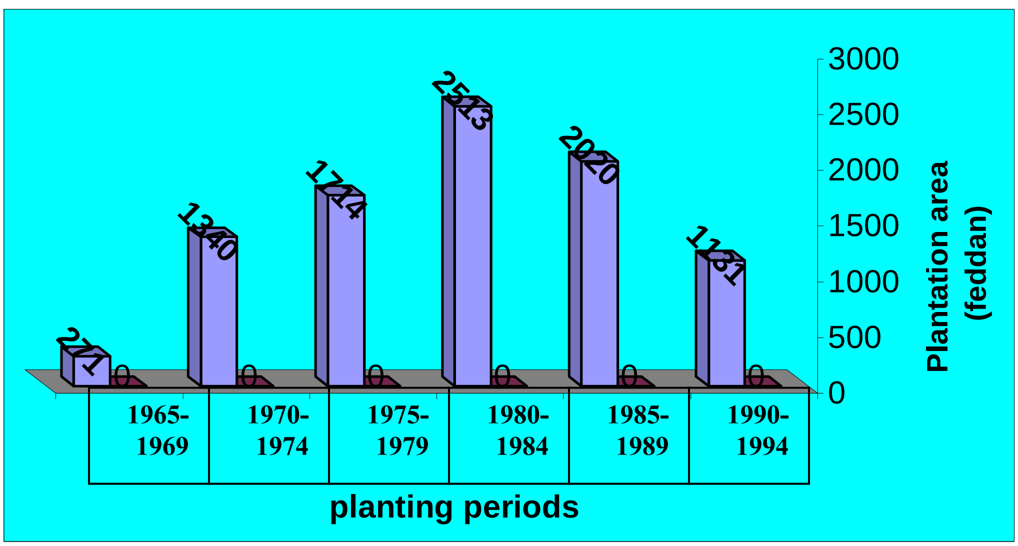
Average area feddan / 5 years	Planting dates	Age years	Plantation area feddan/ 5 years	Deference from average feddan
1920	1965-1969	26-30	271	-1649
	1970-1974	21-25	1340	- 580
	1975-1979	16-20	1714	- 270
	Total		3325	
	1980-1984	11-15	2513	+ 593
	1985-1989	6-10	2020	+1000
	1990-1994	1-5	1131	- 739
	Total		5664	
	bare		2631	

Source: 1994 inventory (FNC, 1994)

Figure 5.3 shows that area / age distribution over the second thirty years rotation (1965-1994) indicates deviations from a stable and balanced structure of area/ age distribution. A wide variation between the actual areas within 5-years groups and the expected average of 1920 - 2000 feddan exists. A clear deviation of the area of the five years age-group from the average (1920 feddan), is noticeable.

Figure 5.3 shows that the area of the oldest five year age-group (26 - 30 years old) was only 271 feddan, while it should have been approximately 1920 feddans.

Figure 5.3 *Acacia nilotica* age class distribution during the second rotation 1965-1994



Source: 1994 inventory (FNC, 1994)

The area of old crop (old 15 years) of the age group 1965-1979 constitutes 29% of the total area of the *Acacia nilotica* plantation, while the young (15 years) age group 1980-1994 constitutes 49% of the total area of the plantation. The bare land constitutes 22 % and together with the young plantation constitutes 71%.

The large area of the bare land indicates that more areas were felled than planted, during 1990-1994. The large area planted during the period 1980-1984 may indicate two points:

- The large area felling program started in 1980.
- The large area regeneration program was carried out during 1980-1984.

However the small area of the old plantation of the age group 26-30 years (planted1965-1969) indicates the continuation of the large scale felling program that exceeded the five years (1965 -1969) period average (1920 feddan) by an area of 1649 feddan.

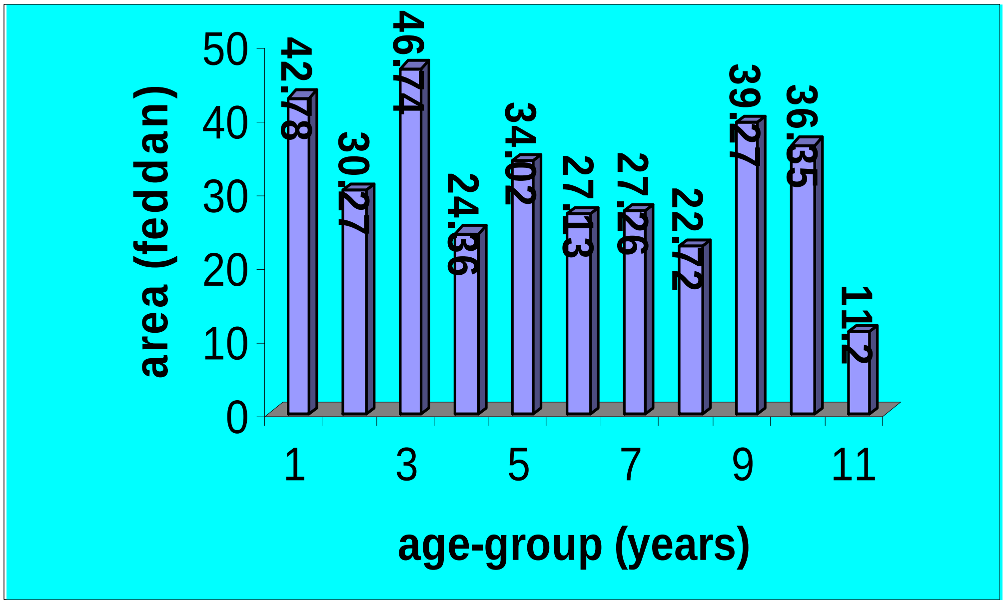
Yield regulation by area during the first 15 years of the second rotation (1965-1979) might have deviated from sustainability and might have caused more felling in stands younger than the rotation age. Hence the plantation area during 1980- 1984 exceeded the average.

5.3.2 Individual forests

The area of Sunt plantations between Sennar to Ruseiris that approximate 11620 feddan exist in small forests distributed along the Blue Nile banks. Each forest contributes in the area/age arrangements over the thirty years rotation but no one forest is organized into 30 compartments to form 30 age groups. However each forest was divided into six to fifteen compartments that form a series of area/age groups. Combination of adjacend forests contribute to 30 years area/age structure.

Lembwa, Gazair and Gelgani forests were chosen to provide the area / age structure over the two rotations. During the first rotation (1935-1964) the Lembwa forest was divided into 13 groups of age with each compartment representing a one year age-group. One or two other forests complement with Lembwa to complete the number of compartments to 30 units of area/age in a series from age one year to age 30 years. Figure 5.4 shows the area/age structure in a series of one year age groups for 13 compartments in Lembwa forest.

Figure 5.4 Division of Lembwa forest into area /age series recorded in 1987 inventory



Source: 1987 inventory

However, the management system which was based on felling and regeneration of single compartments during the first rotation (1935-1964) resulted in the development (of coupes with area between 22.72 feddan (compartment, 10) to 46.74 feddans (compartment, 3), compartment 13 with area of 11.2 feddan is exceptional. Figure 5.4 shows that every compartment was felled and regenerated the same year resulting in 13- age class during the first rotation. However, the system of management practiced in Lembwa during first rotation might have been changed to felling of larger area consisting of more than a single compartment during the second rotation (1965-1994). Or the regeneration might have been delayed. Similar trends of accumulation of clear-felled area to be regenerated the same year have been recorded in many other Sunt plantations. Appendix (1) shows that Gezir has been changed from 19 age-groups to 5 age-groups. Presently Gazair age-groups extends over seven years between age 25 to age 32 instead of 19 years, between age 13 to age 32 years. Appendix (2) shows that Galgani has been changed from 7 ages – group to 3 age-groups and presently the age extends between 11 years to 13 years. Bunzuga has also been changed from 9 age-groups to 6 age-groups.

The exact cause of such change in the age gradation system was not easy to recognize but may be related to the absence of management plans and the dependence of the management on felling program.

5.3.3 Division of the area

In 1987 the Lembwa forest basically composed of 13 compartments with 13 age-group with one year difference, but for practical purposes compartments 1, 2, 3 were considered as one compartment in the Lembwa management records. Hence the number of the compartments reduced to eleven compartments with different areas as shown in the table (5.3).

Table 5.3 Division of area, Lembwa Forest in 1987

Compartment No	Area (hectare)	Bare land	Forest area (feddan)
3	42.78	2.00	40.78
4	30.27	2.59	27.68
5	46.74	9.07	37.67
6	24.36	3.02	21.34
7	34.02	11.81	22.21
8	27.13	2.09	25.04
9	27.26	12.24	15.02
10	22.72	-	22.72
11	39.27	13.25	26.02
12	36.35	5.36	30.59
13	11.20	-	-
Total	269.07	61.43	

Source: (working plan, final year forestry student forestry, U of K 1986)

Table 5.4 Division of area, Lembwa Forest in 2004

Compartment No	Area (feddan)	Area (hectare)	Age (years)
1	67.57	28.15	19
2	55.12	22.96	19
3	65.69	27.37	19
Total	188.38		
4	50.47	21.03	18
5	69.81	29.09	18
Total	122.28		
6	72.35	30.14	15
7	52.11	21.71	15
8	46.81	19.50	15
9	91.07	37.95	15
10	31.95	13.31	15
11	82.45	34.35	15
12	67.57	28.15	15
13	50.25	20.94	15
Total	494.56		
Ground total	803.22	334.65	

Source: Lembwa forest inventory 2004

Table 5.3 shows that the forested area of the compartments after deduction of the bare land resulted in areas with smaller differences than that appeared in Figure 5.4. Since 1987 the area being felled was actually accumulated in larger areas than the annual average. The total area planted reached approximately 803 feddans, but all was planted during three seasons with large area difference between seasons which is becoming clear when areas of any age were expressed in percent of total (Table 5.5).

The area / age structure in Lembwa forest has very much changed over time of the two rotations (1935- 1964 and 1965-1994). The Lembwa forest entered the second rotation with area/age distribution over 13 compartments

(Table 5.3). The plantation entered the third rotation with a wide range of discrepancies in area/age structure and area/age distributed over three years (Table 5.5) range instead of 13 years range.

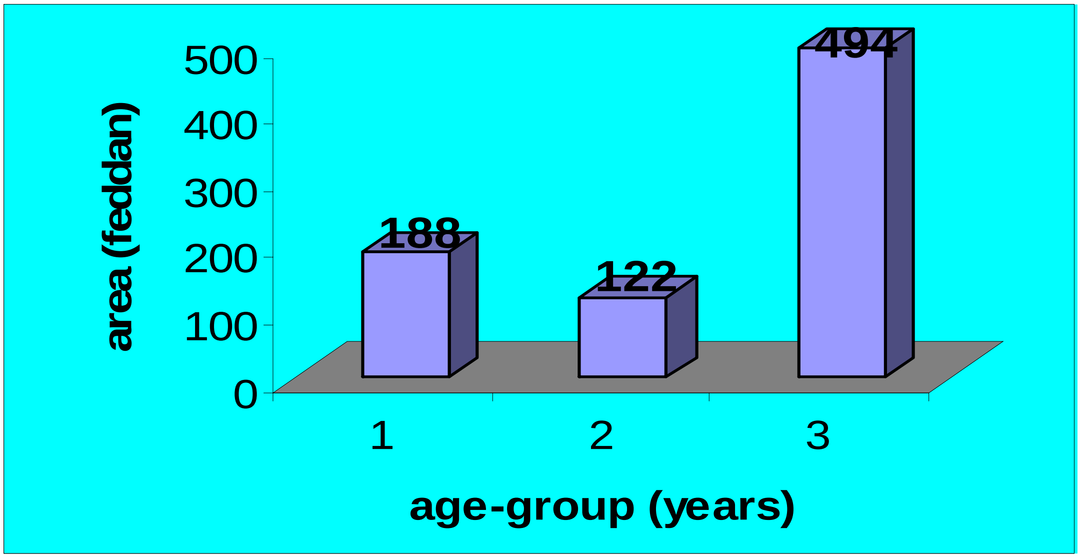
The thirteen groups of area / age structure that was characterized by small annual coupes have been changed to three area / age group. (Table 5.5) presents the area/age structure in percent of total.

Table 5.5 area/age groups in percent of total area

Age years	Area feddan	% of total
19	188	23.4
18	122	15.2
15	494	61.4
Total	804	100

Figure 5.5 shows that no longer the old compartmentation conforms to single compartments in the thirteen age series. The thirteen compartments are delineated into three units of one year age-group.

Figure (5.5) Division of area/age in Lembwa forest as inventoried in 2004



The change in area/age structure in Lembwa (Figure 5.5), Gazair Appendix (1) and Gelgani Appendix (2) forests over time followed considering Lembwa forest, similar trend of the change in area/age structure over time with regard to the total forest rotation (Figure 5.2 and Figure 5.3), the young crop resulting from accumulation of area planted same year in 1989; (15 years old) constitutes 61.4% of the total area of Sunt plantation. Considering the total Sunt forest area along the Blue Nile, the young plantations in addition to the bare land constitute 71%.

The area / age structure at present is showing alarming deviation from the previous normal structure during the first rotation (1935 – 1964) and this is a threat to the sustainability of regular yield.

5.4 Site quality evaluation

Investigation in connection with the construction of site index curves within the flood basins of the Blue Nile for *Acacia nilotica* plantation stands, Hetherington and Elsiddig (1983/84) showed that there are significant differences in growth trends and production potentials between two site quality classes identified on the basis of top height values against age. Both quality classes are at present managed with similar objectives and on the same rotation of thirty years, but they produce timber of different quality and size (Hetherington and Elsiddig 1983/1984).

Tables of top height against age for Sunt plantation on Gerf, Karab and Maya land constructed by Hetherington and Elsiddig (1983/84) used top height at age 20 years as the index for site quality. The values of site index $\geq$ 21 are classified as quality class I (Q.C.I) and the values $<$ 21 are classified as quality class II, (Q.C.II); Table (5.6).

The use of site index curves for site quality assessment at any age is based on the assumption that the value of top height at age, any age, can be extrapolated or interpolated to age 20 years to read the site index value. Appendix (3 and 4). In 1987, Lembwa forest age-group was near end of rotation while in 2004, the plantation age was 15-19 years. Top height at any of these ages can facilitate site index evaluation using table 5.6.

Table 5.6 Site index tables for Sunt along the Blue Nile

	Gerf slopes			Karab slopes and Maya				
Age year	***S.I.25***	***S.I.23***	***S.I.21***	***S.I.25***	***S.I.23***	***S.I.21***	***S.I.19***	***S.I.17***
3	4.18	3.85	3.51	1.57	1.45	1.32	1.19	1.07
4	7.08	6.52	5.94	3.54	3.26	2.98	2.7	2.41
5	9.7	8.93	8.15	5.78	5.32	4.85	4.39	3.93
6	11.98	11.02	10.05	8	7.36	6.72	6.08	5.44
7	13.92	12.81	11.68	10.09	9.29	8.48	7.68	6.86
8	15.58	14.34	13.08	12.01	11.06	10.1	9.14	8.17
9	17	15.65	14.27	13.76	12.67	11.56	10.47	9.36
10	18.24	16.79	15.31	15.34	14.12	12.89	11.66	10.43
11	19.31	17.78	16.21	16.77	15.43	14.08	12.75	11.4
12	20.26	18.65	17.01	18.05	16.62	15.16	13.73	12.28
13	21.1	19.42	17.71	19.22	17.69	16.14	14.61	13.07
14	21.84	20.1	18.33	20.28	18.66	17.03	15.42	13.79
15	22.51	20.71	18.89	21.24	19.55	17.85	16.15	14.45
16	23.1	21.27	19.4	22.13	20.37	18.59	16.82	15.05
17	23.65	21.77	19.85	22.93	21.11	19.27	17.44	15.59
18	24.14	22.22	20.26	23.68	21.79	19.89	18	16.1
19	24.59	22.63	20.64	24.36	22.43	20.47	18.52	16.57
20	***25***	***23***	***21***	***25***	***23***	***21***	***19***	***17***
21	25.38	23.36	21.3	25.89	23.55	21.49	19.45	17.4
22	25.73	23.68	21.6	26.13	24.05	21.95	19.87	17.77
23	26.05	23.98	21.87	26.64	24.52	22.38	20.26	18.12
24	26.35	24.25	22.12	27.12	24.96	22.78	20.62	18.44
25	26.63	24.51	22.35	27.56	25.37	23.15	20.96	18.74
26	26.89	24.75	22.57	27.98	25.75	23.5	21.27	19.03
27	27.13	24.97	22.78	28.37	26.11	23.83	21.57	19.29
28	27.36	25.18	22.97	28.73	26.45	24.14	21.85	19.54
29	27.57	25.38	23.15	29.09	26.77	24.43	22.21	19.78
30	27.77	25.56	23.31	29.42	27.08	24.71	22.37	20
31	27.96	25.74	23.47	29.72	27.36	24.97	22.6	20.21
32	28.14	25.9	23.62	30.02	27.63	25.22	22.83	20.41
33	28.31	26.06	23.76	30.3	27.89	25.45	23.04	20.6
34	28.47	26.2	23.9	30.56	28.12	25.68	23.24	20.78

Source: Elsiddig and Hetherington (1983/1984)

All the compartments in Lembwa forest were inventories in 1987 and in 2004 for site index values and quality class assessment, using top height against age, (Table 5.7)

Table 5.7 the compartments and quality classes in 1987 against 2004 Lembwa forest

Compartment No	Quality Class 1987	Quality Class 2004
1	I	II
2	I	II
3	I	I
4	I	II
5	regeneration	II
6	regeneration	II
7	regeneration	II
8	I	I-II
9	I	I-II
10	II	I-II
11	I	I
12	I	II
13	II	I-II

Source: Lembwa forest inventory 1987 and 2004.

Table 5.7 shows that the value of top height against age in 1987, and 2004 resulted in site quality classes as shown in Table 5.7. Compartments 1, 2, 4, and 12 that were classified as Q.C.I during the 1987 inventory have changed to Q.C.II in the 2004 inventory. Compartment 8 and 9 were Q.C.I in 1987 are becoming partially Q.C.I and partially Q.C.II, only compartments 3 and 11 remained in the Q.C.I.

The change of site quality from class I to class II is assumed to have occurred as a result of human intervention through removal of top height trees. The assumption is based on the observation that most of the remaining stumps in the stands inventoried in 2004 were large stumps expected to be from large trees forming top height. (Plate 1 and 2)

The large stumps in compartment 4 and compartment 8 were measured for diameter at mid-point. Stump diameters were used for estimation of d.b.h and height using equation 5.1 (Eltayeb 1985) and 5.2 (Hetherington and Elsiddig 1983/84) respectively.

$$d_{BH} = 6.1248+0.7396\ d_{GL} \qquad \text{(equation 4.1) (Eltayeb 1985)}$$

Where:

d_{BH} = Tree diameter at breast height.

d_{GL} = Tree diameter at ground level {stump}.

By using equation (5.1), it is possible to calculate tree diameter at breast height if its diameter at ground level is known. This formula could, therefore, be used to calculate the breast height diameters of all trees based on stumps diameter measurements in compartments (4 and 8).

For height determination, the relationship between height and diameter at breast height was used (equation 5.2). This relationship was calculated by using the height – diameter value of *Acacia nilotica* (Hetherington and Elsiddig 1983/84).

The relationship is expressed by the following equation**:**

$$h = 8.09 + 0.53\ d - 0.0033\ d^2 \qquad \text{(equation 4.2)}$$

(Hetherington and Elsiddig 1983/84)

Where:

h = Tree height (m)

d = Tree diameter at breast height (cm).

In compartment 4 the average diameter of stumps in each of the measured sample plots was calculated. The average diameter at beast height for each sample plot was calculated using equation (5.1) and the height was calculated using equation (5.2). The four largest stumps are assumed to correspond to the top height trees whose heights represent site quality measure. The over all average top height of 23.7 meter resulted in site index value at age 20 years to read 25. This value delineates the quality of compartment 4 as Q.C.I. as read in Table 5.5 against 18 years. The same procedure was repeated for calculation of average top height in compartment 8 where an over all average height of 23.5 against age 15 years indicates site index 25 and Q.C.I.

Large stumps of recently felled trees were observed in all compartments approaching final felling, while small-size trees were left. This might be because of heavy thinning, or that successive thinnings continued beyond the age of twenty years.

Intensive selection and creaming of large trees have their impact on stand density, top height values and site quality. However, the effect is different in extent when the first and second rotations are compared. For the first rotation, it seems that selection and thinnings concentrated on small sized trees before the final stocking of the selected and conserved (125 trees / ha) was reached. The management during the first rotation and for some time during the second rotation followed the working plan prescriptions up to 1978 (Jackson 1958; foggie 1968). The management system prescribed and executed the selection of 125 trees per hectare before the third thinning at age 12 years as the best quality trees to be retained for final felling at age 30 years, (Jackson 1958; foggie 1968). The trees then conserved and protected between age 20 to age 30 until they reach the final felling stage (Figure 5.1). That means the 125 trees per hectare are the top height trees being the largest 125 trees per hectare since age 12 years. They provide the value of top height at any age between 20 years to 30 years when the average top height of all the trees was measured.

Table 5.8 is based on grouping of stocking density values and calculation of average top height within each density group in Lembwa forest at age 34 years (1987) for compartments 4 and 8 for Sunt planted in 1953.

Table 5.8 Density group and top height values for compartments 4 and 8 at age 34 years (first rotation).

No of trees / ha	Compartment 4			Compartment 8		
	Top height (m)	S.I	Q.C	Top height (m)	S.I	Q.C
120	-	-	-	29.1	25	I
110	-	-	-	27.2	23	I
100	29.9	25	I	26.8	23	I
90	26.1	23	I	28.0	25	I
80	-	-	-	25.3	23	I
70	28.1	25	I	-	-	-
60	-	-	-	-	-	-
50	23.0	21	I	25.7	23	I

S.I = site index Q.C = quality class

Table 5.8 shows that with decreasing stocking density per hectare, the top height and site index values decreased but limited between site index 25-21 that show all tree measured for height facilitated estimation of the Q.C as Q.C.I. Accordingly the site quality class remained as Q.C.I. It means that the productivity level decreased as from site index 25 to site index 21 but still within Q.C.I. The good management during the past years based on management plans facilitated the conservation of good quality trees retained for final felling but the failure to keep the 125 trees up to age 30 years is reflected in the declining number of the final trees in a range between 120 trees / hectare as best stock, to 50 trees / hectare as the poorest stock. The site index declined from 25 meters at age 20 years to 21 meters at age 20 years with declining density from 125 tree / ha to 50 trees per hectare. Yet the quality class remained as Q.C.I because of the selection and marking of 125 quality trees selected at age 12 years and prevented against cutting. Successive thinning between age 12 years to age 20 years concentrated on trees other than the selected final felling trees (Jackson 1958). Even at lower density the top height trees are still remaining.

During the second rotation, heavy thinning and tree selection resulted in decline of stocking densities at early stages. The densities per hectare recorded at age 18 years for compartment 4 and at 15 years for compartment 8, (Table 5.9) may not be low but the trees were smaller in size than top height trees see Table 5.10. The abandonment of selecting and marking of top height trees at age 12 years was a reason for loosing good quality trees at early ages.

In a sub-sample of 10 sample plots (0.1 ha) in compartment 4 (18 years) and 8 sample plot in compartment 8 (15 years) top height assessment was made on the basis of selected 4 largest trees per 0.1 hectare. The stump diameters were used for d.b.h estimation using equation (5.1) and the estimated d.b.h was used, for height estimation using equation (5.2). The height estimated on the basis of large stumps was used as top height to estimate the site index and the quality class.

Table 5.9 Top height, site index and quality class values for compartments (4 and 8) using top height trees and stumps measurement

compartment	N/ha	Top height from trees	S.I	Q.I	Top height from stump	S.I.	Q.C
4	190	17.9	19	II	23.0	23	I
4	130	16.5	17	II	22.6	25	I
4	130	17.6	19	II	23.1	25	I
4	130	17.0	17	II	23.7	25	I
4	120	18.4	19	II	25.7	21	I
4	120	16.4	17	II	23.4	25	I
4	110	19	19	II	22.5	25	I
4	110	18.7	19	II	22.3	25	I
4	110	18.25	19	II	20.8	21	I
8	120	19.7	23	I	23.7	25	I
8	120	16.4	19	II	23.4	25	I
8	100	17	21	I	23.1	25	I
8	90	16.5	19	II	24.8	25	I
8	80	15.7	17	II	25.3	25	I
8	70	18.7	21	I	23.5	25	I
8	70	18.4	23	I	22.5	25	I
8	50	17.9	21	I	24.6	25	I

Table 5.9 shows that the value of existing top height trees in compartment 4 at age 18 years resulted in site index values between 17-19 classifying the compartment site as Q.C.II. For compartment 8 at age 15, the measured top height classified the site as Q.C.I and Q.C.II.

Moreover, the table indicates that Sunt plantation started to experience heavy thinning resulting in wide variations in stocking densities and most of the large top height trees were removed and left as stumps. However measurements made on the largest four stumps per 0.1 hectare sample plots show that large trees were usually felled. The felled trees are the top height trees as indicated by the estimated top height based on stumps diameter measurements. Measurements on top height obtained from selected large trees resulted in low site index estimation and quality class assessment as Q.C.II. However, the values of top height of the same sample plot, as estimated on the basis of stump diameter are higher than the value of top height obtained from large trees. This indicates that the actual top height trees are usually felled. This is Cleary illustrated by appendix(5) and appendix (6) which show the level of top height obtained from existing trees as compared with the level of top height projected from measurements on stumps using equation 5.1 (Eltayeb 1985) and

equation 5.2 (Hetherington and Elsiddig (1983 / 1984)

5.5 Productivity assessment

The present management practice of *Acacia nilotica* has resulted in failure to attain sustainable production because of the deviation of the plantation from normal structure and the decline of the stocking densities.

The common management practice in the past followed the prescription of the working plans which considered the selection and marking of the final felling crop of 50 trees per Fadden (125 trees per hectare) early in the development stages of the *Acacia nilotica* plantations as an important activity (Jackson 1958). It was an approach for tree improvement since the best growing, large-stemmed trees with straight long boles were selected, usually before the third thinning at age 12 years. Successive thinnings concentrated on removal of trees other than the marked 50 trees per Fadden (125 trees per hectare) until age twenty. In addition to conservation and protection of the 50 trees per feddan for final felling, the thinning schedule followed the guides of the yield table based on the number of trees to be retained according to the principles of age or top height. (Plate 3 and4)

The practice of final felling crop selection and marking was abandoned. At present, any fifty trees per Fadden to be selected for final felling will not represent the quality trees used to be selected in the past, Plate (5 and 6). This might be because of heavy thinning, or that selective thinning is practiced leaving large stumps. Ahmed (1997) observed large stumps of recently felled trees in stands approaching final felling, while small-sized trees are left.

The impact of mismanagement on productivity is reflected in the values of the volume evaluation on the basis of top height using the existing trees and compared with volume obtained as a rustle of stumps diameter projection using compartment 4 and 8.

From the 50 trees in compartment **4** in 2004

Average diameter = 39.7 cm

Average top height = 17.8 m

$$\text{Volume} = \frac{\boldsymbol{\pi}.d^2\ h.\ F}{4 \times 10000} = \frac{3.14\ \times(39.7)^2 \times 17.8\ \times.5}{40000} = 1.1 \text{ meter3}$$

From the 50 trees in compartment **4** in 2004

Average diameter from stump diameter = 44.8 cm

Average top height = 23.7 m

$$\text{Volume} = \frac{\boldsymbol{\pi}.d^2\ h.\ F}{4 \times 10000} = \frac{3.14\ \times(44.8)^2 \times 23.7\ \times.5}{40000} = 1.87 \text{ meter3}$$

The loos equal 41.7 %

From the 50 trees in compartment **8** in 2004

Average diameter = 38.4 cm

Average top height = 16.6 m

$$\text{Volume} = \frac{\boldsymbol{\pi}.d^2\ h.\ F}{4 \times 10000} = \frac{3.14\ \times(38.4)^2 \times 16.6\ \times.5}{40000} = 0.96 \text{ meter3}$$

From the 50 trees in compartment **8** in 2004

Average diameter from stump diameter = 42.7 cm

Average top height =23.5 m

$$\text{Volume} = \frac{\boldsymbol{\pi}.d^2\ h.\ F}{4 \times 10000} = \frac{3.14\ \times(42.7)^2 \times 23.5\ \times.5}{40000} = 1.68 \text{ meter3}$$

The loos equal 42.3 %

Table 5.10 shows the present number of stems per unit area in compartment 4 and 8 using top height value presently measured (Table 5.10). The expected numbers of stems in relation to top height values were calculated using equation 5.3 for Q.C.I and equation 5.4 for Q.C.II (Elsiddig 1980)

Q.C.I: $N = 443.08 - 13.78\ Th$ (equation 5.3) (Elsiddig 1980)

Q.C.II: $N = 483.392 - 16.008\ Th$ (equation 5.4) (Elsiddig 1980)

Equation 5.3 and 5.4 facilitated calculation of the number of trees per feddan according to the present top height values; and also according to the predicted top height values based on measurements on existing stump diameter and application of equation(5.1 Eltayeb 1985) and equation (5.2. Hetherington and Elsiddig (1983 / 1984). Table 5.10 shows that under the existing top height value, and the Q.C.II value for compartment 4 and compartment 8, the expected number of trees per hectare was greater than the existing value. However, under the condition of Q.C.I, the calculated number of stems is compatible with the existing number i-e before execution of thinning at age 20 years. It appears that the number of stems per hectare following the 4th thinning was normal for a Q.C.I site.

Table 5.10 existing number of trees compared to calculated for Q.C.II and Q.C.I

comp	N / ha measured	Top height (m)	No Q.C.II calculated	calculably Top height	No/ ha Q.C.I	No removable	No after 20 years
4	190	17.9	196	23	126	76	50
	130	16.5	219	22.6	131	81	50
	130	17.6	201	23.1	124	74	50
	130	17.0	211	23.7	116	66	50
	120	18.4	188	25.7	89	39	50
	120	16.4	220	23.4	120	70	50
	110	19.0	179	22.5	133	83	50
	110	18.7	183	22.3	136	86	50
	110	18.2	191	20.8	156	106	50
8	120	19.7	167	23.7	116	66	50
	120	16.4	220	23.4	120	70	50
	100	17.0	211	23.1	124	74	50
	90	16.5	221	24.8	101	61	50
	80	15.7	231	25.3	94	44	50
	70	18.7	182	23.5	119	69	50
	70	18.4	189	22.5	133	83	50
	50	17.9	196	24.6	104	54	50

Final felling crop to be left between ages 20 - 30 years, stated as 50 trees per feddan for final crop of Sunt and to continue as 50 trees per feddan between age 20 years and 30 years. The situation for compartment 8 is similar to that of compartment 4 having a normal stocking after the 4th thinning at age 20 years as the number calculated for Q.C.I is close to the existing number of tree per hectare.

It is clear that the number of stems per feddan for compartment 4 and compartment 8 following that execution of the 4th thinning (at age 15 years) indicates reasonable stocking densities for stands approaching age 20 years when the last thinning has to be executed then the number will be reduced to 50 trees per feddan (Table 5.10). However the size-classes of the trees at this stage are smaller than the size of the quality class trees that were removed in a mismanagement of thinning.

Had the thinning been correct following, Jackson (1958) the remaining trees should have been the trees of site quality class I. Assuming that compartment 4 is presently in Q.C.II the existing number of stems per feddan varies from the calculated number by 3 % to 83 %, showing that if compartment 4 and 8 are treated as Q.C.II they appear as over thinned. The existing number is far less than the number that should be existing in the case of Q.C.II.

In fact compartment 4 and 8 are Q.C.I as predicted by the estimated top height value (Tables 5.9 and 5.10)

Assuming that age of compartment 4 is 19 years and should be thinned at age 20 years following Jackson (1958), then the existing number of stems per feddan are compatible with the calculated stem number for compartment 4 under Q.C.I, they are close and reasonably at appropriate number before age 20 years. Table 5.10 shows the expected number to be removed leaving 50 trees per feddan for compartment 4 and compartment 8. However the size of the trees will be smaller than that of the trees during the first rotation

The results indicated that the mismanagement caused loss of the good quality trees as a result of selection felling rather than management. appeared as quality class II in compartment 4 and 8 is in fact quality class I but the trees that would have measured high value of quality class I top height, measured values of existing trees which are not represently the Q.C.I top height trees.

CHAPTER 6
Conclusions and Recommendations

6.1 Conclusions

- A large amount of information that is useful for estimating the productive capacity of the land for same tree species (sunt), related to the different compartments inventories can be integrated to provide a better estimate of the productivity of the various sites.

- This information also has some use for evaluating current and potential productivity for selected sites along the productivity gradient of top height against age.

- Findings reported here agree with past conclusions, that carrying out prescriptive management is important for maintaining productivity through time.

- Site index and yield are always directly correlated. The decline in site index for Sunt growing in the flood basins suggests that poor management has in fact depressed growth rates.

- The application of productivity models (Elsiddig 1980, Hetherington and Elsiddig 1983/1984, Eltayeb1985), facilitated production of top height values from stumps of large trees and improved the calculation of site index values.

- The comparison between the inventory in 1987, 1994 and 2004 indicated that the site productivity appeared to have declined and sustainability attainment is under risk, but in reality site values remained the same while productivity declined because of mismanagement

- The popularity of top height/age relationship as a site indicator is that: Top Height is closely correlated with the ultimate measure of site productivity, Top Height and age are easily determined; Top Height growth is largely unaffected by stand density and Site index provides a numerical expression for site quality

6.2 Recommendations

- Forest planning should consider the development of forest management plans that include consideration of establishment of specific area for management options, defined in Q.C.I and Q.C.II

- Exchange of information, on the results of forest and forest management research and development, is very important to the process of planning for a sustainable forest management.

- When planning for the future of forests on a sustainable basis, planners and managers must balance assets of competing objectives.

- There is an increasing need to make use of the recently developed powerful computer packages, which enable users to use the different tree growth parameters and their interaction objectively in easier manner than before, leading to more development in forest management.

- Estimation of yield can often be improved if the quality of the site is known.

- Site is a useful concept in plantation forestry where it is used to delineate areas according to productivity. The factors which have the greatest bearing on productivity in an area are used in the delineation.

- Site index values use existing parameters of the trees like top height related to age. The values of top height then represent measurable indicators of site and productivity.

- Management planning can be improved when homogeneous land areas are delineated on maps. Better documentation of these areas will also reduce the potential loss of information.

- Estimates of site can be used to identify land that is more appropriate for different uses. Hence better land use policies and practices are encouraged.

References

Ahmed.E.A 1967. On thinning *Acacia nilotica* stands along the Blue Nile. Sudan Silva III (21) 40-45.

Ahmed.E.F.1997. Investigation on the Dieback of *Acacia nilotica* in the Blue Nile area associated with the bark beetle, *Chrysobothris dorsata*. M.Sc Thesis, Department of forest Conservation and Protection, Faculty of forest, University of Khartoum.

Asmann, E, 1970. the principles of forest yield studies. Pergamon press. Oxford, New York, Toronto, Sydney. Braunschweig. 506 pp.

Bennett, F, A. 1970. Variable density yield tables for managed stands of natural slash pine. USDA. For Serv. Res. Note,SE-141.

Bickford, C, A. 1957. Stocking normality and measurement of stand density. J. For. 55:99-104.

Booth, G.A (1949). Fung *Acacia nilotica* working plan for 1949-1958, Forests Department, Ministry of Agriculture, Sudan.

Boyer, W, D. 2001. A generation change in site index for naturally established long leaf pine on a south Alabama coastal plain site. Southern Journal of applied forestry, 25 (2): 88-92.

Briegleb, P, A 1952. An approach to density measurement in Douglas fir. J. of For. 50:529-536.

Bruce, D. 1926. A method of preparing timber yield tables. J. Agric Res. 32: 543-557.

Bruce, D. and Schumacher, F. X. 1950. Forest menstruation. 3rd ed. McGraw-Hill Co. New York 483 PP.

Bunting, A, H. and lea, J, D. 1962. The soils and vegetation of the Fung, east central Sudan. J. ecol. 50:529-558.

Carmean, W, H. 1975. Forest site quality evaluation in the United States. Advances in Agronomy 27:209-269.

Carron, L, T. 1968. An outline of forest menstruation. Australian Natural University press, Canberra. 224 P.

Curtis, R, O. 1972. Yield tables, past and present. J. For. 70: 28-32.

Elsiddig.E.A 1980**.** The production of stem and branch volume of *Acacia nilotica* in the Fung region in the Sudan. Thesis submitted to the University of Wales in candidature for the degree of Philosophiae Doctor;243 pp

Elsiddig. E. A. and Abdelgadir, A Y. 1998**.** Carbon fluxes in relation to land-use change and forest. un published paper submitted to the workshop June 1998, on carbon dioxide inventory, Higher council for Environment and Natural Resource. Khartoum

Elsiddig. E. A. 2002**.** The management of *Acacia nilotica*. L plantation along the Blue Nile flood basins in Sudan for sustainable production: A Review. U. of K. J . Agric. Sci. 10(1):119 - 130

Elsiddig. E. A and J. C. Hetherington 1985**.** The stem and branch volume of *Acacia nilotica* in the Fung region in the Sudan. University college of North Wales, Department of forestry and wood science, publication

Elsiddig. E. A and Hamid. K. 2000. Management of trees for farmland rehabititation and development. Paper presented at the Workshop on management of farmland rehabilitation and development. Khartoum – Friendship hall, Sudan, 27 October-7 November 2000.

Eltayeb ,A.M (1985) konstruktion einer Ertragstragstufelfuer die Baumart *Acaica nilotica* (construction of a yield table for the tree species (*Acaica nilotica)* Ph.D Thesis, faculty of forestry, TU Dresden.

Foggie, 1968. Northren Fung working plan 1968-1978. volume1. forestDepartment, Khartoum.

FOSA, July 2001**.**Sudan country outlook / FNC-FAO. forest outlook study for Africa

Heatherington and Elsiddig 1983/1984.

Husch, B., Miller, C.I and Beers, T.W. 1972**.** Forest menstruation. The Ronald press co. New York.

Jackson, J. K. (1958)**.** Fung working plan for 1959-1968, for. Dep. (Sudan) For. Bull. No.3. 71pp.

Kocher D. and John. W.L Blanc**,** university of California cooperative Extension, Proceedings of the conference on coast red wood forest Ecology and management (Arcata, CA, Jun 18-20 /1996).

Nyland.R, 1983, Silviculture class notes. Suny college of Environment Science and forestry. Syracuse, N.Y. paper Florida forestry information-forest management. http//www.sfrc.ufl.edu/Extension/ffws/sd.htm

Site productivity working group 2001 SIBEP sampling and data standards (verision 5.1). B. C. ministry of forests Victoria, B. C.

Splechtna, B, E. 2001. Height growth and site index model for pacific *silver fir* in southwestern British Columbia. B.C Journal of Ecosystems and management 1 (1): 1-14.

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